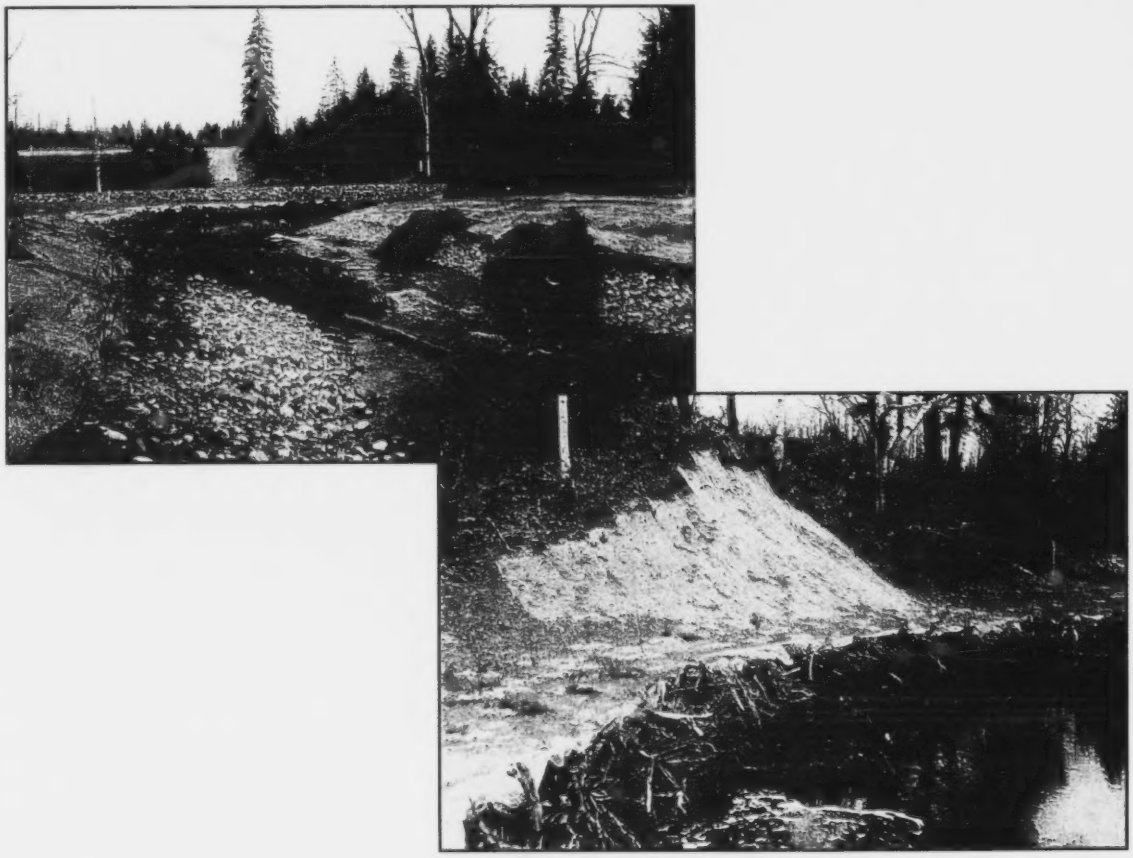
# Vegetative Bank Stabilization

# A Review of Various Soil Bioengineering Projects



Ministry
of
Transportation
Ontario

# Vegetative Bank Stabilization

## A Review of Various Soil Bioengineering Projects

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March 2000

# Contents


**Forward** ..... 3

**Contributors** ..... 3

**Basic Principles of Vegetative Bank Stabilization or Soil Bioengineering** ..... 4

**Bioengineering Plant Material** ..... 8

**Species Suitable for Rooting in Bioengineering Structures** ..... 9

**Case Studies** ..... 10-45

- Aberfoyle Creek ..... 10
- Black Ash Creek ..... 12
- Clair Creek ..... 14
- Fisher's Creek ..... 16
- Groff Mill Creek ..... 18
- Highland Creek ..... 20
- Kolb Creek ..... 22
- Laurel Creek ..... 24
- Leamy Creek ..... 26
- Little East River ..... 28
- Mad River ..... 30
- Mississauga Road ..... 32
- Mooney's Bay ..... 34
- Osler Bluff ..... 36
- Parliament Hill ..... 38
- Sawmill Creek ..... 40
- Sheridan Creek ..... 42
- Thamesville ..... 44

**Summary Observations** ..... 46

**Summary Recommendations** ..... 48

**References** ..... 50

## Foreword

The purpose of reviewing eighteen vegetative soil stabilization projects across Ontario was to determine whether or not these projects could sustain themselves over a long period of time and perform as well as, or better than, traditional hard engineering solutions.

The review is not a quantitative, technical analysis of each project, but rather a qualitative overview of the project, the design solution and an assessment of its success several years after installation. Most of these projects were constructed in the early 1990's, a few of them are more recent.

The projects represent a variety of design venues in slope and stream bank rehabilitation by all levels of government and government agencies.

## Contributors

Dr. Nancy Cain, formerly of the Research and Development Office of the Ministry of Transportation Ontario, started this project in 1994. Dr. Cain identified the various projects and established the original contacts with the project managers. She arranged and conducted the original field reviews with Ministry vegetation specialists and the respective project managers.

The various project designers and managers of each project spent considerable time and effort in providing information and showing the completed projects on site. Particular appreciation should be given to:

Glenn Harrington, Principal, Harrington Hoyle Limited

Maureen Miller, formerly Harrington Hoyle Limited

Sylvia Strobl, Ontario Ministry of Natural Resources

Rick Grillmayer, Nottawasaga Valley Conservation Authority

Bob Hosler (retired) and Jim Clark (retired), formerly National Capital Commission

Tim Rogers, Ministry of Transportation Ontario

George Finnigan (retired) formerly, Ministry of Transportation Ontario

## Basic Principles of Vegetative Bank Stabilization or Soil Bioengineering

In this report, the terms Vegetative Bank Stabilization and Soil Bioengineering are used synonymously and interchangeably. Soil Bioengineering is the most commonly accepted term to describe the procedure.

Soil Bioengineering is a soil stabilization technique that uses living plants to provide control of erosion prone soil areas on sloped banks and stream channel banks. Whereas traditional engineering solutions employ hard inert materials to stabilize slopes and banks, bioengineering uses natural materials in fabricated structures and live, dormant cuttings of suitable plant species.

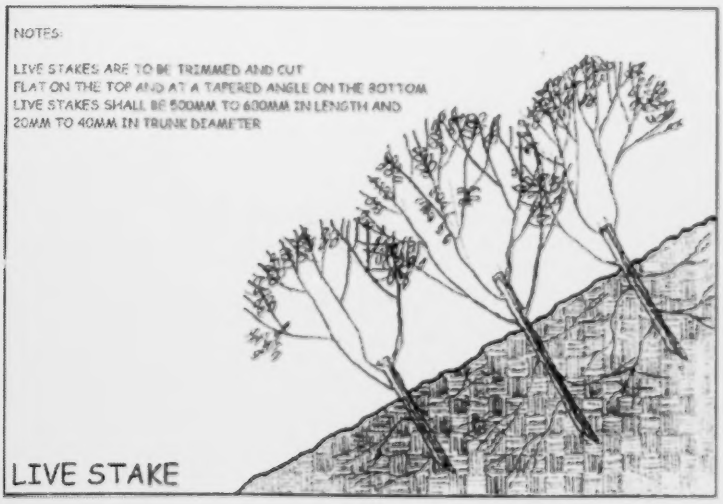
The various bioengineering techniques can be used alone, modified or in combination to provide control of earth areas immediately after construction as well as over the long term. Bioengineering techniques employ aspects of engineering, using some hard inert materials, such as logs or rock, in combination with live, natural materials such as live stakes, live cuttings or rooted cuttings.

Application of the techniques is site specific and should be designed by someone familiar with engineering principles and natural science expertise. The basic techniques include the following:

### Live Stakes

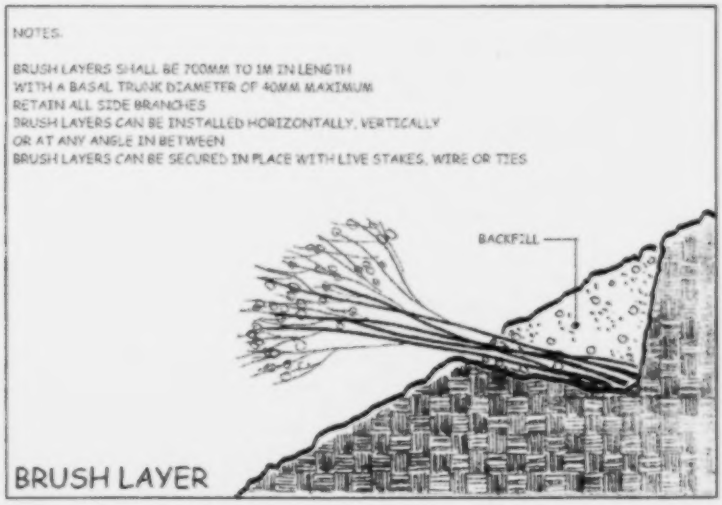
Live cuttings are taken from rootable woody plant stock during the dormant plant period. There is a very limited selection of plant species that will root from live woody cuttings.

These live stakes are used to consolidate and reinforce the earth area. As the stakes develop roots and top growth, they establish themselves on a site and provide erosion control through development of their rooting system as well as reducing ground moisture through transpiration.


NOTES:
LIVE STAKES ARE TO BE TRIMMED AND CUT
FLAT ON THE TOP AND AT A TAPERED ANGLE ON THE BOTTOM
LIVE STAKES SHALL BE 500MM TO 600MM IN LENGTH AND
20MM TO 40MM IN TRUNK DIAMETER
LIVE STAKE

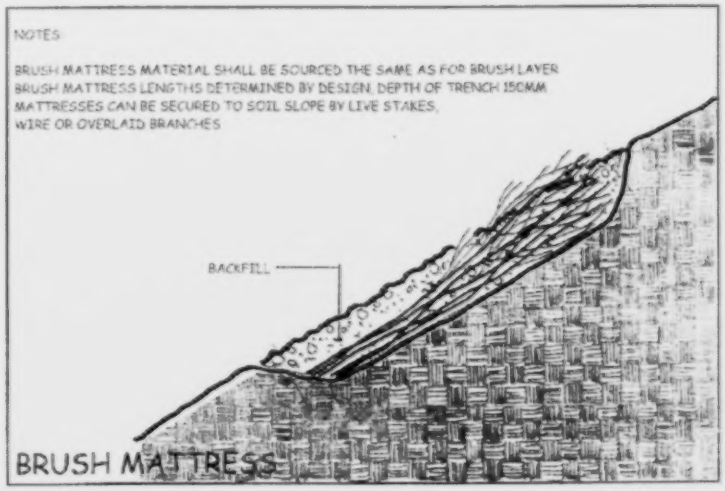
## Brush Layers

Live soft branches of suitable host plants are the best source of material for brush layers. These branches are fresh cut when the plant is dormant and placed into prepared trenches with the growing tips out. The fresh cut ends are placed into the prepared trenches, sometimes anchored in place and backfilled. Brush layers can be installed vertically, horizontally or at any angle in between, depending on the site and design solution. The live cut branches root into the soil retarding surficial runoff erosion. The protruding section of the branch produces top growth to sustain the plant.


NOTES:
BRUSH LAYERS SHALL BE 700MM TO 1M IN LENGTH
WITH A BASAL TRUNK DIAMETER OF 40MM MAXIMUM
RETAIN ALL SIDE BRANCHES
BRUSH LAYERS CAN BE INSTALLED HORIZONTALLY, VERTICALLY
OR AT ANY ANGLE IN BETWEEN
BRUSH LAYERS CAN BE SECURED IN PLACE WITH LIVE STAKES, WIRE OR TIES
BACKFILL
BRUSH LAYER

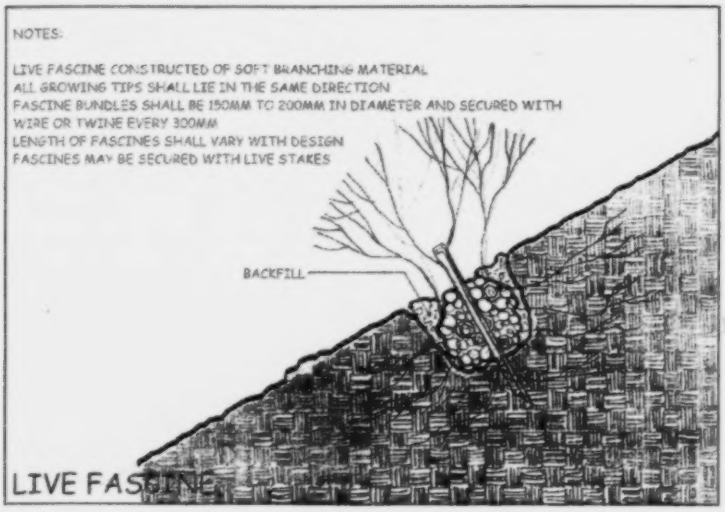
## Brush Mattresses

Live soft branches of suitable host plants are also the best source of material for brush mattresses. These branches are also fresh cut from dormant plants and placed on the ground very close together, so that the entire area is covered. The fresh cut ends are usually dug into the soil and secured by stakes, wire or overlaid branches. The entire brush mattress is usually covered with a light layer of soil to promote rooting.


NOTES:
BRUSH MATTRESS MATERIAL SHALL BE SOURCED THE SAME AS FOR BRUSH LAYER
BRUSH MATTRESS LENGTHS DETERMINED BY DESIGN, DEPTH OF TRENCH 150MM
MATTRESSES CAN BE SECURED TO SOIL SLOPE BY LIVE STAKES,
WIRE OR OVERLAID BRANCHES
BACKFILL
BRUSH MATTRESS

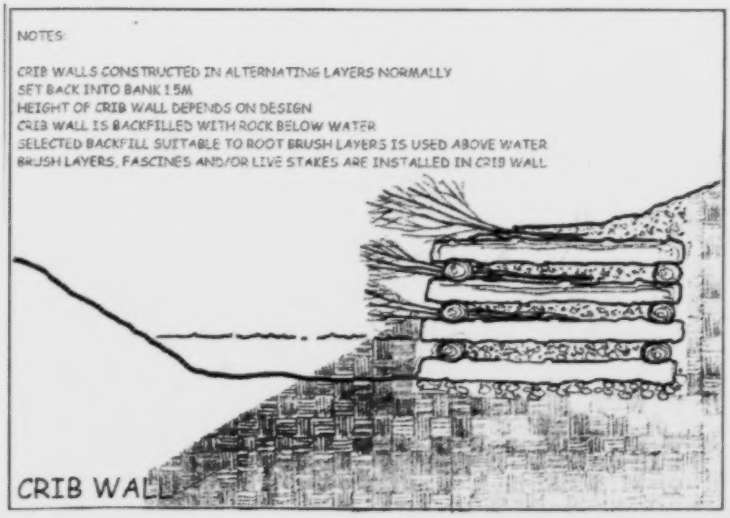
## Live Fascines

Live fascines are constructed of live soft branches from suitable host plants. The thin flexible branches are fresh cut from dormant plants and tied together with the end tips all facing one way in long (up to several metres in length) bundles. The bundle diameter varies based on the design specifications, however the fascine bundles are laid into trenches and secured with live stakes or wire anchors. The trenches are backfilled and the bundles of branches eventually root. Trench design and layout is determined by the design solution.


NOTES:
LIVE FASCINE CONSTRUCTED OF SOFT BRANCHING MATERIAL
ALL GROWING TIPS SHALL LIE IN THE SAME DIRECTION
FASCINE BUNDLES SHALL BE 150MM TO 200MM IN DIAMETER AND SECURED WITH
WIRE OR TWINE EVERY 300MM
LENGTH OF FASCINES SHALL VARY WITH DESIGN
FASCINES MAY BE SECURED WITH LIVE STAKES
BACKFILL
LIVE FASCINE

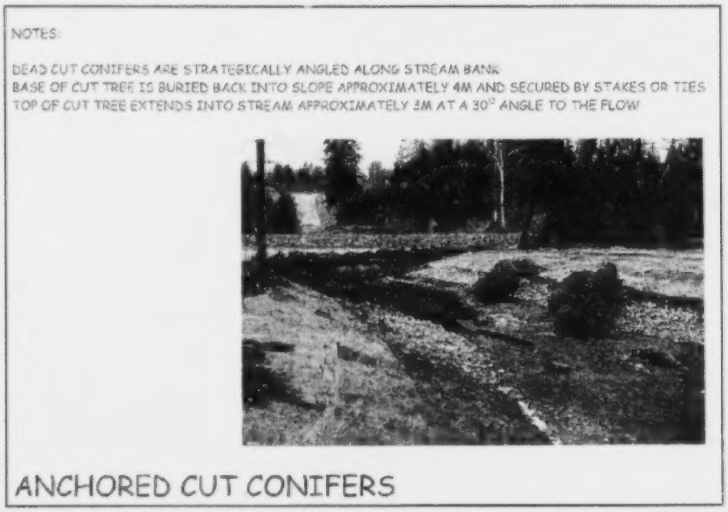
## Live Crib Walls

Live crib walls are used on stream banks to protect the bank from erosion caused by waves or flow. Crib walls are usually constructed of round timber logs in alternating layers set back into the bank and secured by wire or spikes. The crib wall structure is then backfilled with soil and usually lined with a geotextile. Live stakes or live rooted plants are placed in the soil between the voids in the crib wall structure.


NOTES:
CRIB WALLS CONSTRUCTED IN ALTERNATING LAYERS NORMALLY
SET BACK INTO BANK 1.5M
HEIGHT OF CRIB WALL DEPENDS ON DESIGN
CRIB WALL IS BACKFILLED WITH ROCK BELOW WATER
SELECTED BACKFILL SUITABLE TO ROOT BRUSH LAYERS IS USED ABOVE WATER
BRUSH LAYERS, FASCINES AND/OR LIVE STAKES ARE INSTALLED IN CRIB WALL
CRIB WALL

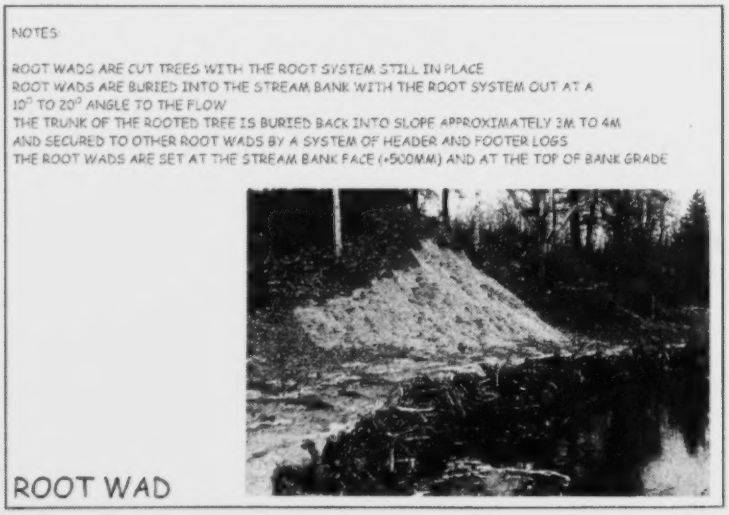
## Anchored Cut Conifers

Dead, cut conifers are set into the stream banks at strategic locations to control the stream bank from water flow during peak flow and peak levels. The dead trees are usually wired together and secured back into the slope by stakes or ties.


NOTES:
DEAD CUT CONIFERS ARE STRATEGICALLY ANGLED ALONG STREAM BANK
BASE OF CUT TREE IS BURIED BACK INTO SLOPE APPROXIMATELY 4M AND SECURED BY STAKES OR TIES
TOP OF CUT TREE EXTENDS INTO STREAM APPROXIMATELY 3M AT A 30° ANGLE TO THE FLOW
ANCHORED CUT CONIFERS

## Root Wads

Root wads are also used along stream banks to control water flow during peak flow and peak levels. Coniferous trees are normally selected for root wads. A root wad consists of the majority of a tree's root system, excavated intact, usually with a 3 m to 5 m length of the trunk still attached. The root wads are set back into the bank with the root system facing out towards the stream flow. The trunk portion of the root wad is secured back into the stream bank usually 3 m to 5 m in and held in place by header and footer logs. The header and footer logs are secured to the root wads by wire, steel bars or other means, thus producing a continuous length of joined root wads.


NOTES:
ROOT WADS ARE CUT TREES WITH THE ROOT SYSTEM STILL IN PLACE
ROOT WADS ARE BURIED INTO THE STREAM BANK WITH THE ROOT SYSTEM OUT AT A
10° TO 20° ANGLE TO THE FLOW
THE TRUNK OF THE ROOTED TREE IS BURIED BACK INTO SLOPE APPROXIMATELY 3M TO 4M
AND SECURED TO OTHER ROOT WADS BY A SYSTEM OF HEADER AND FOOTER LOGS
THE ROOT WADS ARE SET AT THE STREAM BANK FACE (+500MM) AND AT THE TOP OF BANK GRADE
ROOT WAD

## Bioengineering Plant Material

As there are many variations of common names for plants, botanical nomenclature has been used throughout this document to refer to plant material. This is particularly true of the *Salix* (Willow) genus where there is so much hybridization or cross-breeding that there are many species of Salix shrubs and they are all very similar and difficult to identify.

The use of plants in soil bioengineering also raises the issue of non-native plant material. Plants can be non-native to a continent, a region, an ecosystem or a locality. Concern for the introduction of invasive, non-native plants must be tempered with some common sense about the use of the plant, its ability to survive as a bioengineering material as well as its potential to invade an area and over-populate the site. In many bioengineering sites, the designers are aiming towards establishment of a condition that will encourage indigenous, invasive woody and herbaceous plant material. This is naturalization. There is nothing wrong with naturalization, plants that have the ability to grow and thrive in a specific locale will do so, plants that cannot survive will die. Obviously, the extreme condition has to be taken into account. Single species or monocultural domination of a site is not healthy or environmentally sustainable. Biodiversity should be a factor to consider when planning bioengineering work.

One of the limiting factors for soil bioengineering in Ontario is the restricted palette of woody plant material available for use. Woody plants are best for bioengineering applications because of the more vigorous structure of the roots and their greater capacity to secure soil and reduce erosion. As most bioengineering applications use unrooted cuttings, one of the most important factors for the material is the ability to readily root without horticultural intervention, such as rooting hormones, specialized rooting medium or controlled environmental conditions. These plants have to quickly root in-situ in a wide variety of soils, sites and conditions. The Ministry of Transportation, Ontario experimented with direct rooting of woody cuttings as a research project in the early 1990's. The results indicated that only species of Populus, Cornus, Salix and Physocarpus had the ability to root directly from fresh, dormant cuttings. Work by others in bioengineering applications has also shown that Salix is by far the best genus for use in bioengineering work. Populus and Cornus species will also root, but not as quickly or abundantly.

Plants used in the bioengineering case studies and referred to in this document are shown here along with their common names.

**Salix (Willow)**

| Scientific Name | Common Name |
|---|---|
| Salix nigra | Black Willow |
| Salix alba | White Willow |
| Salix chrysocoma | Golden Weeping Willow |
| Salix eriocephala | Diamond or Cotton Headed Willow |
| Salix discolor | Pussy Willow |
| Salix exigua | Sandbar Willow |
| Salix lucida | Shining Willow |
| Salix petiolaris | Slender Willow |
| Salix pentandra | Laurel Willow |

**Cornus (Dogwood)**

| Scientific Name | Common Name |
|---|---|
| Cornus stolonifera | Red Osier Dogwood |
| Cornus racemosa | Grey Dogwood |

**Populus (Poplar)**

| Scientific Name | Common Name |
|---|---|
| Populus alba | White or Silver Poplar |
| Populus balsamifera | Balsam Poplar |
| Populus tremuloides | Quaking or Trembling Aspen |
| Populus deltoides | Cottonwood |
| Populus canadensis | Carolina Poplar |
| Populus X 'varieties' | Various hybrid Poplars |

## Species Suitable for Rooting in Bioengineering Structures

Source: Dr. Nancy Cain, formerly of the Research and Development Office, Ministry of *Transportation Ontario.*

As a result of discussions and observations during field trips to established bioengineering projects and following ministry research on the direct rooting of woody cuttings, the following species are suitable for direct rooting applications in Ontario. It is recommended to use at least three species, in case one does not survive.

**Salix (Willow) — Tree form**

| Scientific Name | Common Name |
|---|---|
| Salix nigra | Black Willow (native) |
| Salix alba | White Willow (introduced from Europe, naturalized) |
| Salix chrysocoma | Golden Weeping Willow (introduced from Europe/Asia, naturalized) |

**Salix (Willow) — Shrub form**

| Scientific Name | Common Name |
|---|---|
| Salix eriocephala | Diamond or Cotton Headed Willow (native) |
| Salix discolor | Pussy Willow (native) |
| Salix exigua | Sandbar Willow (native, colonizes sites by rhizomes) |
| Salix lucida | Shining Willow (native) |
| Salix petiolaris | Slender Willow (native, similar to S. gracilis) |
| Salix pentandra | Laurel Willow (introduced from Europe) |
| Salix purpurea | Basket Willow (introduced from Europe, naturalized) |
| Salix gracilis | Slender Willow (native, similar to S. petiolaris) |

**Populus (Poplar) — Tree form**

| Scientific Name | Common Name |
|---|---|
| Populus alba | White or Silver Poplar (introduced from Europe, naturalized) |
| Populus balsamifera | Balsam Poplar (native, does not root as vigorously as the hybrid poplars) |
| Populus tremuloides | Quaking or Trembling Aspen (does not root readily from stem cuttings) |
| Populus deltoides | Cottonwood (native) |
| Populus canadensis | Carolina Poplar (hybrid between P. deltoides and P. nigra) |
| Populus X 'varieties' | Various hybrid Poplars of different clones, may be more vigorous in rooting and growth) |

**Cornus (Dogwood) — Shrub form**

| Scientific Name | Common Name |
|---|---|
| Cornus stolonifera | Red Osier Dogwood (native, does not root as vigorously as willow on dry or vegetated sites) |

**Physocarpus (Ninebark) — Shrub form**

| Scientific Name | Common Name |
|---|---|
| Physocarpus opulifolius | Common Ninebark (native) |

# Site Name: Aberfoyle Creek

## Type of Bioengineering Structure:

- ■ **Live Stakes**
- ❑ Brush Layers
- ❑ Brush Mattresses
- ❑ Live Fascines
- ❑ Live Crib Walls
- ❑ Anchored Cut Conifers
- ❑ Root Wads

## Success of the Structure:

- ❑ Poor
- ■ **Fair**
- ❑ Good
- ❑ Excellent

## Site Details:

| | |
|---|---|
| **location:** | Guelph, Hwy. 6 north of Hwy. 401 |
| **contact:** | Murray Purcell, MTO, London<br>(519) 271-5942 |
| **date of construction:** | May 1, 1980 |
| **cost of construction:** | Unknown |
| **first site visit:** | October 25, 1994 |
| **second site visit:** | October 19, 1999 |

**site characteristics:** Aberfoyle Creek runs parallel to Hwy. 6 on the west side of the right-of-way, it crosses Hwy. 6 and heads east. The creek rehabilitation extended down the parallel section of the creek on the west side of Hwy. 6.

**site problems:** Aberfoyle Creek is a cold water creek. During construction of Hwy. 6 shading of the creek was recommended as part of environmental mitigation.

**soil type:** Sandy loam.

**hydrology:** Aberfoyle Creek has continuous flow with seasonal fluctuation in water levels.

**type of bioengineering structure:** Live stakes used along the east side of creek between creek and highway.

**plant material:** Live 1-3 year old cuttings of Salix nigra, 600 mm to 900 mm in length, were taken from a fallen tree near Stratford, cut and planted in the same day.

**post construction problems:** Trees suffered somewhat from exposure to winter and highway conditions.

**site conditions at first visit:** 60% success of live stakes. Hydro cut down trees on east side of highway and some damage to trees on west side from exposure and winter maintenance activity.

**site conditions at second visit:** Salix have grown to 10 m to 13 m in height and 500 mm to 600 mm in diameter. The understory has filled in with various indigenous vegetation including Thuja (Cedar) and Larix (Larch) species.

**survival of plant materials:** Survival is fairly good 19 years after planting, considering the location. The Salix trees have died back from exposure and storm breakage, but for the most part they have survived. There is no evidence of regeneration from the Salix trees but the understory has filled in with invasive indigenous plants.

**success of the structure:** Fair. This was a fairly simple bioengineering structure utilizing live whip planting. However, the plant material has survived and the creek is shaded. The creek water still appears to run clear and the creek survives in close proximity to a 4 lane highway.

## Aberfoyle Creek

Site photograph (1999) of creek overgrown with vegetation parallel to Hwy. 6.

Site photograph(1999) showing dense growth of overstory and stream bank.

# Site Name: Black Ash Creek

## Type of Bioengineering Structure:

- ■ **Live Stakes**
- ❑ Brush Layers
- ❑ Brush Mattresses
- ❑ Live Fascines
- ■ **Live Crib Walls**
- ❑ Anchored Cut Conifers
- ❑ Root Wads

## Success of the Structure:

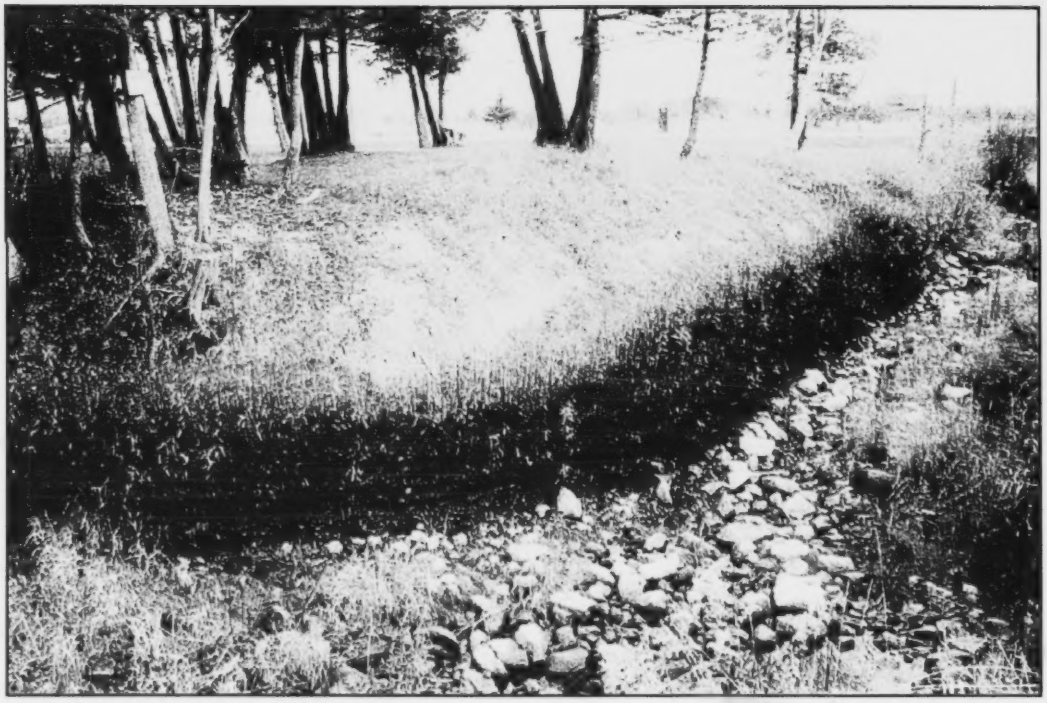
- ❑ Poor
- ❑ Fair
- ❑ Good
- ■ **Excellent**

## Site Details:

| | |
|---|---|
| **location:** | Collingwood, Nottawasaga Twp. Rd. 10 and Poplar Side road |
| **contact:** | Rick Grillmayer, Nottawasaga Valley Conservation Authority (705) 424-1479 |
| **date of construction:** | November 25, 1993 |
| **cost of construction:** | $6,200 |
| **first site visit:** | November 14, 1994 |
| **second site visit:** | November 23, 1999 |

| | |
|---|---|
| **site characteristics:** | Historical traditional channelization of the creek had shunted the flow into a high gradient trapezoidal roadside ditch with steep side banks (1:1) |
| **site problems:** | Previous armouring had been removed and both channel banks and stream bed experienced severe erosion. |
| **soil type:** | Sand and silty/sand banks, streambed is clay. |
| **hydrology:** | Erratic flow, sometimes intermittent with peak flows estimated at 3 to 4 cubic m/sec. |
| **type of bioengineering structure:** | Live crib wall and live stakes used along a 34 m length, 1.2 m high, 2 m deep at base and 1.4 m deep at top. Crib wall was sloped back and horizontal face logs were overlapped. Crib wall and rip-rap in stream bed. The stream bank on the road side was repaired in 1995 with traditional hard engineering materials. |
| **plant material:** | Live 1 to 3 year old cuttings were harvested locally and used within a day of cutting. Species included Salix eriocephala, Salix lucida and Salix exiqua as well as Cornus stolonifera. Antiwash geojute used to hold an annual rye/oat seed mix to the soil above the crib wall. |
| **post construction problems:** | Some erosion of crib wall fill material, not significant enough to affect the integrity of the crib wall. |
| **site conditions at first visit:** | Good survival of plant material (>75%). Live stakes only survived in wetter areas. Excellent growth from material in live crib wall, shoots were about 600 mm long. |
| **site conditions at second visit:** | Crib wall is still in place, there is no erosion and good plant growth. The concrete block wall installed in 1995 is starting to show evidence of undercutting. |
| **survival of plant materials:** | Salix eriocephala is the most successful of the species. Salix lucida grows better in wetter areas. Salix exiqua could not compete. There are some Cornus stolonifera still on site. All plants have a multitude of branches averaging about 1 m in length. |
| **success of the structure:** | Excellent. The crib wall is still functioning very well, the plant material has established both by root and top growth and erosion is minimal. The installation of the concrete block wall on the road side of the stream provides a good comparison of techniques. |

## Black Ash Creek



Site photograph (1994) showing crib wall construction, rip rap channel, live stakes and geojute.

Site photograph (1999) showing the stabilized bioengineered stream bank on the left and the concrete block retaining wall installed in 1995.

# Site Name: Clair Creek

## Type of Bioengineering Structure:

- ❑ Live Stakes
- ■ **Brush Layers**
- ■ **Brush Mattresses**
- ■ **Live Fascines**
- ❑ Live Crib Walls
- ❑ Anchored Cut Conifers
- ❑ Root Wads

## Success of the Structure:

- ❑ Poor
- ■ **Fair**
- ■ **Good**
- ❑ Excellent

## Site Details:

| | |
|---|---|
| **location:** | Waterloo, Craigleith Drive east off Fischer-Hallman Rd. |
| **contact:** | Glenn Harrington, Harrington and Hoyle Ltd. (905) 294-8282 |
| **date of construction:** | Early 1990's |
| **cost of construction:** | $25,000 |
| **first site visit:** | November 1, 1994 |
| **second site visit:** | October 13, 1999 |

**site characteristics:** The park site was previously forested. Clair Creek had 2:1 stream bank slopes that were eroding. The creek traverses a residential area and is in a recreational park and semi-natural area.

**site problems:** Stream bank erosion seemed to be caused by undercutting and heavy pedestrian traffic.

**soil type:** Sand.

**hydrology:** Dry stream bank slopes, low flow, some seasonal fluctuation.

**type of bioengineering structure:** Brush layers, live fascines and brush mattresses at bottom of the slope were employed during re-establishment of the creek channel.

**plant material:** Live cuttings of Salix species and Cornus species.

**post construction problems:** None.

**site conditions at first visit:** Unknown.

**site conditions at second visit:** Cornus stolonifera have populated stream slopes and there is heavy growth along the stream banks.

**survival of plant materials:** Good regeneration of Cornus stolonifera from root mass. There is not much Salix in evidence.

**success of the structure:** Fair to good. There is some bank undercutting at the flow stress points which the designer claims creates 'dynamic stability, energy dissipation and wildlife habitat'. The undercutting is not serious and the bioengineering structure has held the creek flow.

Overall photograph (1999) of stream showing excellent growth of Cornus (Dogwood) shrubs on both banks.

Close-up photograph (1999) of bank showing branching structure growing out of original fascines and brush layers.

# Site Name: Fisher's Creek

## Type of Bioengineering Structure:

- ■ **Live Stakes**
- ❑ Brush Layers
- ❑ Brush Mattresses
- ❑ Live Fascines
- ❑ Live Crib Walls
- ❑ Anchored Cut Conifers
- ❑ Root Wads

## Success of the Structure:

- ❑ Poor
- ❑ Fair
- ■ **Good**
- ❑ Excellent

## Site Details:

| | |
|---|---|
| **location:** | Hespeler, Hwy. 24 north of Hwy. 401 |
| **contact:** | Murray Purcell, MTO, London (519) 271-5942 |
| **date of construction:** | April 1, 1991 |
| **cost of construction:** | Unknown |
| **first site visit:** | October 25, 1994 |
| **second site visit:** | October 13, 1999 |

**site characteristics:** Fisher's Creek crosses Hwy. 24, the floodplain lies below and adjacent to the highway.

**site problems:** Erosion and seasonal flooding along creek and floodplain.

**soil type:** Clay.

**hydrology:** Dry stream bank slopes, good flow in creek.

**type of bioengineering structure:** Live stakes used throughout floodplain on MTO property.

**plant material:** Live cuttings of Salix alba and Salix chyrsocoma were cut to 600 mm in length. Branches were winter cut from roadside trees, stored in unheated trailer in wet peat in garbage bags and allowed to freeze. Crown vetch mix seeded throughout the floodplain.

**post construction problems:** Some of the trees disappeared initially, either trampled or taken by hikers. Rodents damaged some of the trees and bait stations were placed for rodent protection.

**site conditions at first visit:** Planting on one side of the creek has been trampled by hikers or pulled out. There is scattered rodent damage, however salix trees are not as susceptible to rodents as the other planted material.

**site conditions at second visit:** The understory has developed with invasive herbaceous perennials, but there is no woody regeneration in evidence.

**survival of plant materials:** Plants tend to be taller on exposed southwest side and shorter on shadier side. Salix trees are growing well, 6 m to 9 m in height and 100 mm to 150 mm in diameter. The planted Acer (Maple) rooted saplings are not performing as well as the Salix live stakes.

**success of the structure:** Good. There is shading of the creek, the plant root mass is controlling stream bank erosion. The trees have provided useful cover and are doing well.

# Fisher's Creek

Site photograph (1999) of Fisher's Creek from bridge showing Salix (Willow) trees.

Close-up photograph (1999) of Salix (Willow) trees showing trunk size, canopy and understory.

# Site Name: Groff Mill Creek

## Type of Bioengineering Structure:

- ■ **Live Stakes**
- ❑ Brush Layers
- ■ **Brush Mattresses**
- ■ **Live Fascines**
- ■ **Live Crib Walls**
- ❑ Anchored Cut Conifers
- ❑ Root Wads

## Success of the Structure:

- ❑ Poor
- ❑ Fair
- ❑ Good
- ■ **Excellent**

## Site Details:

| | |
|---|---|
| **location:** | Cambridge, Hwy. 8 north of Hwy. 8/24 Intersection |
| **contact:** | Glenn Harrington, Harrington and Hoyle Ltd. (905) 294-8282 |
| **date of construction:** | May 1, 1992 |
| **cost of construction:** | $127,500 |
| **first site visit:** | November 1, 1994 |
| **second site visit:** | October 13, 1999 |

**site characteristics:** Groff Mill Creek was channelized and engineered earlier to accommodate residential and industrial land development. The watershed has no stormwater management, therefore the stream exhibits flash floods, high flood peaks and sediment loads.

**site problems:** Seasonal flooding, stream bank and bed instability erosion and undercutting.

**soil type:** Sandy loam.

**hydrology:** Flash flooding, high flood peaks and sediment loads.

**type of bioengineering structure:** Brush mattresses (72 m²), live fascines (145 m), live crib wall (20 m) and live stakes all used in conjunction with an overall natural channel design incorporating natural design principles including vortex weirs, riffles and plunge pool.

**plant material:** Live cuttings were cut and collected locally in April, bundled and stored in cold storage to retard bud break. Species composition was 60% Salix shrub species and 40% Cornus stolonifera.

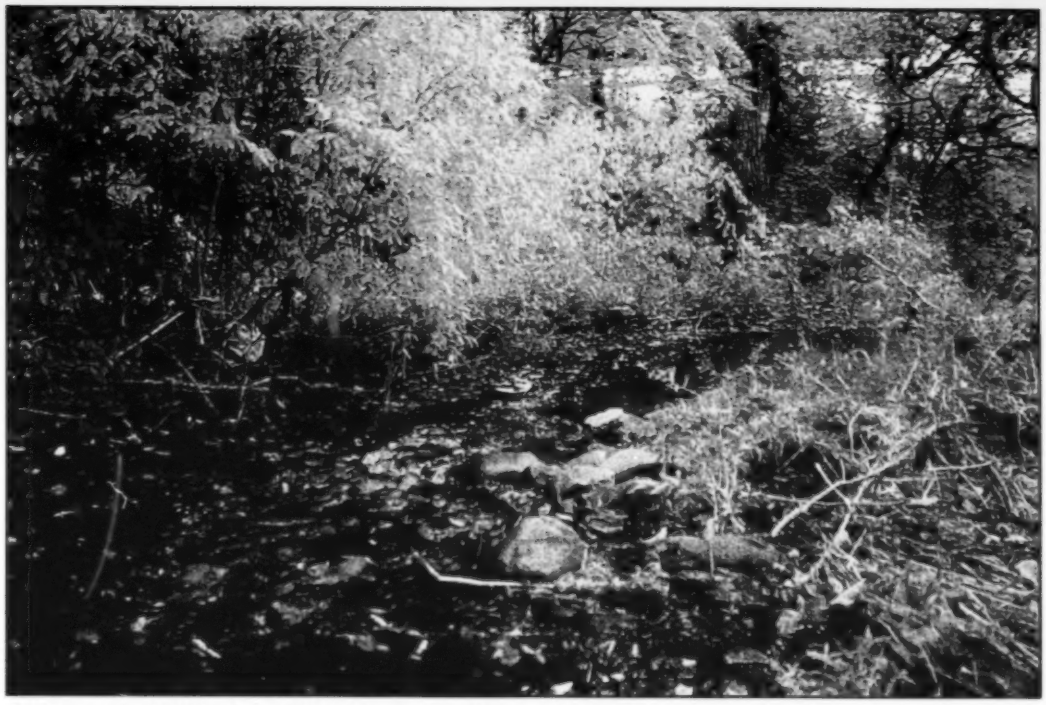
**post construction problems:** Some cutting of bioengineering structures by residential owners with their lawnmowers.

**site conditions at first visit:** There is some failure of fascines due to poor installation and lawnmower damage. The brush mattress material has grown reasonably well. No major stream bank erosion or undercutting.

**site conditions at second visit:** The natural channel design has resulted in good flow and level control, with minimal stream bank erosion. Salix species have grown to 3 m in height from the fascines and live stakes.

**survival of plant materials:** Salix and Cornus species are abundant. There is some invasion from indigenous herbaceous perennials and woody plants.

**success of the structure:** Excellent. The stream bank has stabilized, the natural channel design and the bioengineering structures have provided consistent control and a better environment. The stream is evolving as a dynamically stable system.



Photograph (1999) of Groff Mill Creek showing fascines along stream bank.

Close-up photograph (1999) of top growth regeneration from fascines.

# Site Name: Highland Creek

## Type of Bioengineering Structure:

- ❑ Live Stakes
- ■ **Brush Layers**
- ❑ Brush Mattresses
- ■ **Live Fascines**
- ❑ Live Crib Walls
- ❑ Anchored Cut Conifers
- ❑ Root Wads

## Success of the Structure:

- ❑ Poor
- ❑ Fair
- ■ **Good**
- ❑ Excellent

## Site Details:

| | |
|---|---|
| **location:** | Scarborough, Progress Rd. east off Markham Rd., south of Hwy. 401 |
| **contact:** | City of Toronto, Scarborough District, Works and Environment (416) 396-7689 |
| **date of construction:** | October 1, 1991 |
| **cost of construction:** | Unknown |
| **first site visit:** | November 24, 1994 |
| **second site visit:** | October 27, 1999 |

| | |
|---|---|
| **site characteristics:** | Commercial development adjacent to a steep (1:1) slope leading down to Highland Creek. Highland Creek has been lined with large armour rock and banks are well stabilized. Slope has been built up in layers using a plastic geogrid. |
| **site problems:** | Potential eroding slope above creek, development of commercial property close to creek included underground parking close to the slope. |
| **soil type:** | Varies, slope material predominantly clay. |
| **hydrology:** | Slope well drained. |
| **type of bioengineering structure:** | Brush layers enclosed by plastic geogrid and webbing, live fascines were installed down drainage course. |
| **plant material:** | Live cuttings consisted of four Salix species, including Salix nigra, Cornus stolonifera and Populus balsamifera. The slope was seeded with turfgrasses. |
| **post construction problems:** | Slope heated well into winter by underground garage structure, dumping of garbage from parking lot above. |
| **site conditions at first visit:** | There is approximately 25 to 40% survival of plant material. There is minimal slope erosion. |
| **site conditions at second visit:** | The plant material has established itself on the slope. There is some invasion of indigenous herbaceous perennials and woody plants. |
| **survival of plant materials:** | Salix and Cornus shrub species populate the slope, they have rooted well from the brush layers and fascines. There is one large Populus tree on the slope, about 10 m in height and 300 mm in diameter. |
| **success of the structure:** | Good. The steep slope has held well and stabilized with minimal erosion. Plant material has rooted well and the presence of invasive woody and herbaceous perennial plants will help to further populate the slope. |

# Highland Creek

Photograph (1999) of the slope showing the growth of plant materials.

Photograph (1999 ) of Highland Creek showing armour stone stream bank and the vegetated slope.

# Site Name: Kolb Creek

## Type of Bioengineering Structure:

- ❑ Live Stakes
- ■ **Brush Layers**
- ■ **Brush Mattresses**
- ■ **Live Fascines**
- ❑ Live Crib Walls
- ❑ Anchored Cut Conifers
- ❑ Root Wads

## Success of the Structure:

- ❑ Poor
- ❑ Fair
- ❑ Good
- ■ **Excellent**

## Site Details:

| | |
|---|---|
| **location:** | Kitchener, Forwell Drive south off Victoria St. |
| **contact:** | Glenn Harrington, Harrington and Hoyle Ltd. (905) 294-8282 |
| **date of construction:** | October 1, 1993 |
| **cost of construction:** | Unknown |
| **first site visit:** | November 7, 1994 |
| **second site visit:** | January 25, 2000 |

| | |
|---|---|
| **site characteristics:** | Kolb Creek is a floodway into the Grand River, rip rap was installed on an outside bend for comparison, concrete channel changed to bioengineered channel at various locations along the creek. |
| **site problems:** | A new floodway was needed to handle increased development when an old dam was removed. |
| **soil type:** | Till material consisting of sand, sediment and cobble, varies greatly. |
| **hydrology:** | Low controlled flow, in floodplain. |
| **type of bioengineering structure:** | Brush layers were placed in crushed rock rip rap, 1.2 m deep and 1.5 m back into soil slope. Live fascines used on the outside bend of creek, brush mattresses used at the toe of slope. Erosion blanket placed in floodplain and pond stone was used in riffles. |
| **plant material:** | Live cuttings were harvested locally, stored in water and used within three days of cutting. Species included Salix eriocephala, Salix pentandra, Salix nigra and Cornus stolonifera. |
| **post construction problems:** | None. |
| **site conditions at first visit:** | Stream banks are stable and the riffles and pools are developing well. |
| **site conditions at second visit:** | The structures have stabilized well over time, there is good control of stream bank undercutting and minimal erosion. |
| **survival of plant materials:** | Excellent top and root growth, almost 100% uniform Salix shrub growth from fascines. Top growth is up to 3 m in height. |
| **success of the structure:** | Excellent. The channel has naturalized very well and has narrowed well. No evidence of erosion and creek chub are now spawning in the creek. |

Overall photograph (2000) of creek showing regeneration of stream bank material from fascines.

Close-up photograph (2000) of creek showing Salix (Willow) shrub growth from fascines.

# Site Name: Laurel Creek

## Type of Bioengineering Structure:

- ☐ Live Stakes
- ☐ Brush Layers
- ☐ Brush Mattresses
- ■ **Live Fascines**
- ■ **Live Crib Walls**
- ☐ Anchored Cut Conifers
- ☐ Root Wads

## Success of the Structure:

- ☐ Poor
- ☐ Fair
- ☐ Good
- ■ **Excellent**

## Site Details:

| | |
|---|---|
| **location:** | Waterloo, Bechtel Park, Hwy. 86 and University Ave. |
| **contact:** | Glenn Harrington, Harrington and Hoyle Ltd. (905) 294-8282 |
| **date of construction:** | October 1, 1993 |
| **cost of construction:** | $750,000 |
| **first site visit:** | November 1, 1994 |
| **second site visit:** | January 25, 2000 |

**site characteristics:** The Laurel Creek valley is in a Class 6 wetland, adjacent to an old urban dump and a sanitary sewer that runs parallel to the creek. Laurel Creek outlets to the Grand River.

**site problems:** The wide meandering of Laurel Creek exposed old landfill garbage and was threatening to expose a sanitary sewer installation. There were also stagnant areas of the creek creating bad odours.

**soil type:** Variable fill material.

**hydrology:** Realignment has improved flow, no stagnation, some spring seepage along the bank.

**type of bioengineering structure:** Crib wall structures constructed on critical sections of stream bank and live fascines were installed along the creek as well as at the top and bottom of the crib wall.

**plant material:** Live cuttings consisted of various species of Salix shrubs and Cornus stolonifera. Turfgrass was seeded outside of stream banks.

**post construction problems:** None.

**site conditions at first visit:** The plant material in the crib wall had survived and the live fascines were growing well.

**site conditions at second visit:** The crib wall is still structurally sound and in good condition. There is some washout and undercutting of soil from the crib wall as well as evidence of rodent burrowing.

**survival of plant materials:** Salix and Cornus species are doing well. There is good growth at the top of the crib walls as well as along the stream bank. Height of plants is approximately 900 mm with an abundance of suckering.

**success of the structure:** Excellent. The crib wall structures are still in place, the plant material is established and continues to grow and root.

Close-up photograph (2000) of crib wall structure showing regeneration of Salix (Willow) and Cornus (Dogwood) shrubs on top, and earth voids underneath the crib wall.

Overall photograph (2000) of creek showing crib wall, Salix (Willow) and Cornus (Dogwood) shrubs on top of crib wall and along the bottom in the creek channel.

# Site Name: Leamy Creek

## Type of Bioengineering Structure:

- ■ **Live Stakes**
- ■ **Brush Layers**
- ❑ Brush Mattresses
- ■ **Live Fascines**
- ■ **Live Crib Walls**
- ❑ Anchored Cut Conifers
- ❑ Root Wads

## Success of the Structure:

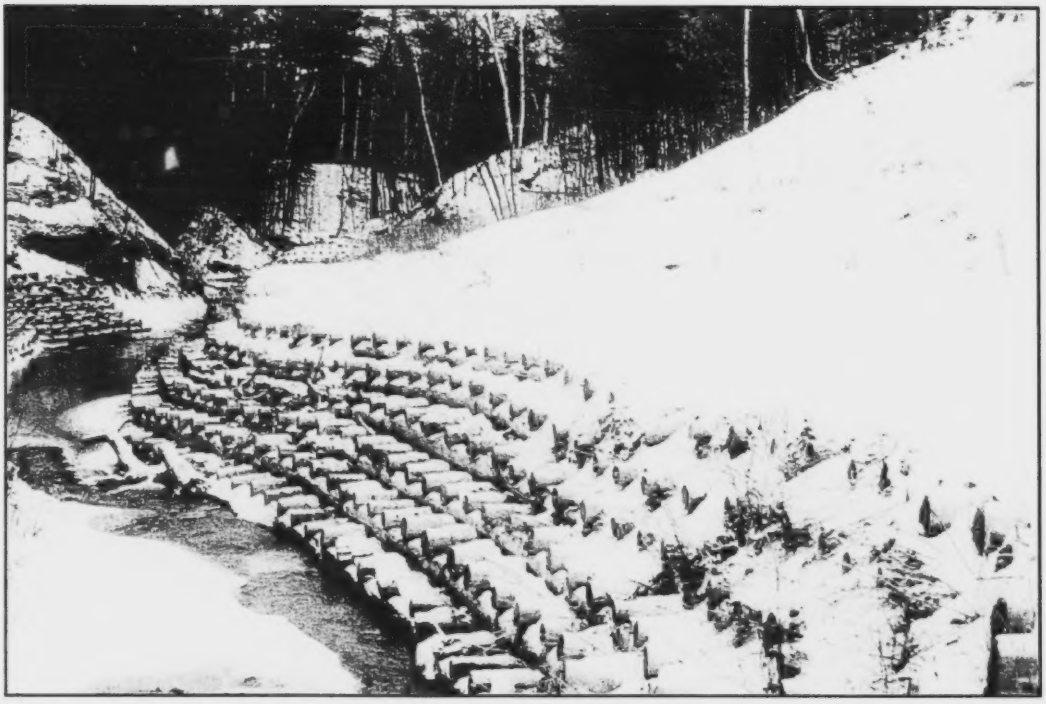
- ❑ Poor
- ❑ Fair
- ■ **Good**
- ❑ Excellent

## Site Details:

| | |
|---|---|
| **location:** | Hull, PQ Route 5 and Hautes des Plaines, on the edge of Gatineau Park |
| **contact:** | Gerry Lajeunesse, National Capital Commission (613) 239-5139 |
| **date of construction:** | November 1, 1992 |
| **cost of construction:** | $250,000 |
| **first site visit:** | December 1, 1994 |
| **second site visit:** | October 6, 1999 |

| | |
|---|---|
| **site characteristics:** | The site is a large (1 ha) bowl-shaped slope leading down to Leamy Creek, it is wooded on both sides with residential development all around the plateau on top of the slope. |
| **site problems:** | Parent soil on the slope site is leida clay, an unstable material that can lead to slope failure. Leamy Creek also had severe stream bank erosion, undercutting and washouts. |
| **soil type:** | Leida clay, topsoil cover. |
| **hydrology:** | Spring seepage along the bowl-shaped slope, seasonal peak flows in creek. |
| **type of bioengineering structure:** | Horizontal brush layering, live fascines, and live cuttings were placed on the slope, also wooden stop logs were wired into slope. A wooden crib wall and vertical brush layering were installed along the creek bank. |
| **plant material:** | Live cuttings of Salix shrub species and Cornus stolonifera were used in the crib wall and live fascines. Populus species were used in the brush layering on the slope. All plant material was locally collected from NCC property, stored outside and covered with snow. Legume and clover mix was hydro seeded on the site. |
| **post construction problems:** | Some washing out of crib wall, one main erosion gully developed in the middle of the bowl. |
| **site conditions at first visit:** | There was a 30 to 50% success of the plant material on both the bowl slope and the crib wall. There was good growth along most sections of the crib wall. |
| **site conditions at second visit:** | There is better growth on the east side of bowl slope and the brush layer trenches are quite noticeable for their growth. The crib wall material has not grown that much and there is some undercutting of crib wall by peak flow and levels. |
| **survival of plant materials:** | Plant growth at the site has stabilized. Growth is not bad, consisting mostly of Salix and Populus species growing from the fascines and live stakes on the slope. Cornus stolonifera is growing in and around the crib wall. The bowl slope has a good growth of trefoil and some invasive perennials. |
| **success of the structure:** | Good. Minor erosion on the bowl slope with one main gully. The crib wall has held the creek bank with some undercutting, but overall the bioengineering structure has performed well. |

## Leamy Creek



Photograph (1994) of Leamy Creek crib wall construction and erosion-prone leida clay slope above.

Photograph (2000) of the slope in foreground showing re-growth from brush layering; Leamy Creek at lower right showing crib wall.

# Site Name: Little East River

## Type of Bioengineering Structure:

- ❑ Live Stakes
- ❑ Brush Layers
- ❑ Brush Mattresses
- ❑ Live Fascines
- ❑ Live Crib Walls
- ■ **Anchored Cut Conifers**
- ■ **Root Wads**

## Success of the Structure:

- ❑ Poor
- ❑ Fair
- ■ **Good**
- ❑ Excellent

## Site Details:

| | |
|---|---|
| **location:** | Huntsville, parallel to Hwy. 11, 7.9 km north of Hwy. 60 |
| **contact:** | Tim Rogers, MTO, North Bay (705) 497-5466 |
| **date of construction:** | September 1, 1998 |
| **cost of construction:** | $266,000 |
| **first site visit:** | November 4, 1998 |
| **second site visit:** | August 23, 1999 |

**site characteristics:** The Little East River is considered a coldwater system that supports a brook trout population. The river meanders through a wooded valley.

**site problems:** The river needed to be realigned approximately 300 m to enable widening of Hwy. 11. Natural channel design and bioengineering techniques were used as a mitigative and compensation factor.

**soil type:** Mostly sandy silts, some organics and some gravel.

**hydrology:** Little East River has good flow and high seasonal peaks. Groundwater level is high in valley.

**type of bioengineering structure:** Root wads and buried coniferous trees were used in conjunction with natural channel design principles to stabilize the river banks. A rock berm was constructed between the realigned river and Hwy. 11. Rock riffles were constructed in the river.

**plant material:** Root wads were coniferous trees removed from site or imported with a minimum root wad of 1.5 m and minimum length of 5 m. Buried coniferous trees were removed from site and were a minimum of 9 m in length. The area was seeded with a special turfgrass mixture (Festuca rubra, Poa pratensis, Lolium perenne and Poa plaustris) and erosion control blanket.

**post construction problems:** One failure area adjacent to root wads was reinforced with river run stone. Minor damage to landscape plants and adjacent trees from beaver.

**site conditions at first visit:** First site visit was immediately after construction and the site was in good condition with no evidence of erosion.

**site conditions at second visit:** The bioengineered structure had settled in, there was minimal undercutting of root wads and the cut conifers were still in place. Some of the rooted landscape plantings had died and there was evidence of beaver damage to more mature trees.

**survival of plant materials:** All of the bioengineering structure was cut, dead plant material. The associated landscaping was planted on the floodplain and appeared to be surviving.

**success of the structure:** Good. The root wads are holding well, there has been some dislodging of soil material from around the root wads, but it is not significant. The cut conifers are in place and the associated landscaping should develop well, providing the beaver leave them alone.

Photograph (1998) of the initial installation of buried conifers and river run rock.

Photograph (1999) of the bend in river showing root wads anchored into bank, landscape plantings behind the root wads and the rock berm.

# Site Name: Mad River

## Type of Bioengineering Structure:

- ❑ Live Stakes
- ■ **Brush Layers**
- ❑ Brush Mattresses
- ❑ Live Fascines
- ■ **Live Crib Walls**
- ❑ Anchored Cut Conifers
- ❑ Root Wads

## Success of the Structure:

- ❑ Poor
- ■ **Fair**
- ❑ Good
- ❑ Excellent

## Site Details:

| | |
|---|---|
| **location:** | Creemore, Riverside Drive north of County Rd. 9 |
| **contact:** | Rick Grillmayer, Nottawasaga Valley Conservation Authority (705) 424-1479 |
| **date of construction:** | October 15, 1993 |
| **cost of construction:** | $30,000 |
| **first site visit:** | November 14, 1994 |
| **second site visit:** | November 16, 1999 |

| | |
|---|---|
| **site characteristics:** | The Mad River runs adjacent to Riverside Drive along this section. The water flow and seasonal peak flows have created erosion problems at the toe of the roadside slope. |
| **site problems:** | Water erosion down slopes created surface erosion, sediment transportation into the river resulting in fish habitat degradation. Toe of slope also eroding due to river flow. |
| **soil type:** | Gravel till and backfill material. |
| **hydrology:** | Mad River has good year round flow, high seasonal peaks. Surface and sub-surface seepage flows. |
| **type of bioengineering structure:** | Live crib wall installed at the toe of slope was constructed of local logs. Crib wall was secured with steel t-bar stakes driven vertically along the crib wall face. A large stone and gravel layer was installed at water level. Four brush layers were installed from the top of the crib wall back to undisturbed slope. A plastic drainage pipe was installed vertically down the slope to handle main drainage flow. |
| **plant material:** | Live cuttings consisted of Salix petiolaris, Salix eriocephala, Salix alba, Populus species and Cornus stolonifera. All material was cut locally and stored no more than 2 to 3 days in water. |
| **post construction problems:** | Minor slope erosion and some undercutting of the crib wall during peak flows. Top layer of the brush layering was taken out early after construction by peak flows. Brush layering re-installed in 1995. |
| **site conditions at first visit:** | There was poor survival (10%) of plant material. The crib wall structure is still in place. |
| **site conditions at second visit:** | There is fairly good growth of the surviving plant material, the slope is stable and the crib wall, while somewhat battered, has held the toe of slope. |
| **survival of plant materials:** | Plant growth on the slope has stabilized. Growth is not bad, consisting mostly of Salix species and Cornus stolonifera growing from the brush layers. There is some invasion from indigenous woody and herbaceous perennial plants. |
| **success of the structure:** | Fair. The crib wall has shown signs of undercutting and battering from peak flows and spring runoff. The steel t-bars are bent and the crib wall has bulged and buckled in places, but it is performing adequately. The plant material, while not abundant, is growing with the increasing root mass helping to stabilize the slope. |

Overall photograph (1999) of the slope and river showing woody regeneration from brush layers and invasion of Rhus (Sumac) shrubs.

Close-up photograph (1999) of crib wall at toe of slope showing crib wall structure, steel t-bars and brush layers.

# Site Name: Mississauga Road

## Type of Bioengineering Structure:

- ■ **Live Stakes**
- ■ **Brush Layers**
- ❑ Brush Mattresses
- ■ **Live Fascines**
- ❑ Live Crib Walls
- ❑ Anchored Cut Conifers
- ❑ Root Wads

## Success of the Structure:

- ❑ Poor
- ❑ Fair
- ■ **Good**
- ❑ Excellent

## Site Details:

| | |
|---|---|
| **location:** | Terra Cotta, Regional Rd. 1, north of Regional Rd. 9, south of Credit River |
| **contact:** | Glenn Harrington, Harrington and Hoyle Ltd. (905) 294-8282 |
| **date of construction:** | November 1, 1993 |
| **cost of construction:** | $50,000 |
| **first site visit:** | November 15, 1994 |
| **second site visit:** | September 27, 1999 |

**site characteristics:** The site is a long, high, steep (1.8 to 2:1) cut slope located on the east side of Mississauga Road.

**site problems:** The roadside slope had eroded and sediment had been transported onto Mississauga Road.

**soil type:** Alternate layers of clay, silt, sand and gravel, low fertility.

**hydrology:** Seepage and percolation along seams in slope.

**type of bioengineering structure:** Brush layers were placed along the slope and buried about 1 m back into the slope. Live fascines were located along every third layer and in drains. Live stakes were also planted throughout the slope. Sub drains were placed along the top and toe of slope.

**plant material:** Live cuttings of Salix species, Populus species and Cornus stolonifera were used in fascines and brush layers. Annual ryegrass was used as a cover to encourage natural species invasion and regeneration.

**post construction problems:** Some slope gully erosion and minor rilling.

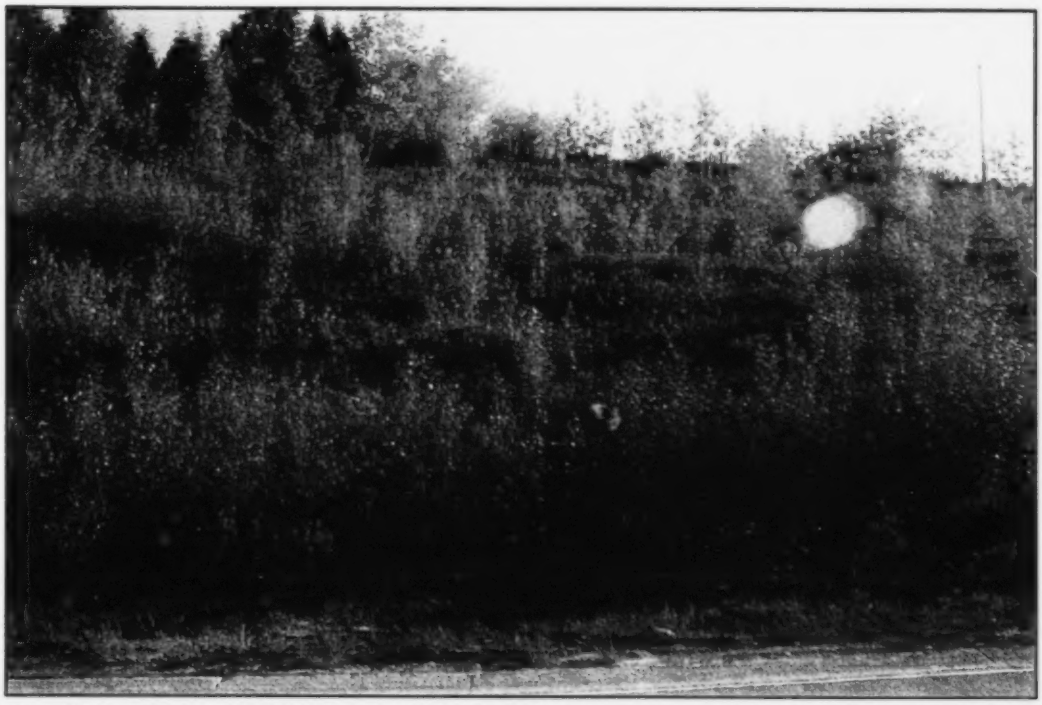
**site conditions at first visit:** The bioengineering structure was holding the slope, the woody plants had rooted but had limited top growth, probably due to the lack of nutrients and organic material on the site.

**site conditions at second visit:** There is good growth of the Populus species from the fascines and brush layers. The slope looks good overall with little erosion and only one main gully remaining.

**survival of plant materials:** The plant material is established and growing fairly well. Populus species are doing the best, growing from the lateral fascines and brush layers along the slope. There is heavier woody growth on the lower one third of the slope, probably due to higher moisture levels.

**success of the structure:** Good. The bioengineered structure is still in place and holding the slope. The drainage fascines have channelled the runoff and there is only one main channel subject to surficial erosion.

## Mississauga Road



Overall photograph (1999) of the slope showing the horizontal parallel lines of fascines and the Populus (Poplar) tree growth.

Close-up photograph (1999) of one horizontal fascine showing the bundled branches and resultant top growth.

# Site Name: Mooney's Bay

## Type of Bioengineering Structure:

- ■ **Live Stakes**
- ❑ Brush Layers
- ❑ Brush Mattresses
- ■ **Live Fascines**
- ❑ Live Crib Walls
- ❑ Anchored Cut Conifers
- ❑ Root Wads

## Success of the Structure:

- ❑ Poor
- ❑ Fair
- ■ **Good**
- ❑ Excellent

## Site Details:

| | |
|---|---|
| **location:** | Ottawa, Melba Cres., east off Prince of Wales Dr. on Rideau River |
| **contact:** | Gerry Lajeunesse, National Capital Commission (613) 239-5139 |
| **date of construction:** | October 1, 1994 |
| **cost of construction:** | $19,000 |
| **first site visit:** | December 1, 1994 |
| **second site visit:** | October 6, 1999 |

**site characteristics:** The site is a small, fairly steep slope leading from a flat open space in a residential area down to the water, adjacent to Mooney's Bay off the Rideau River.

**site problems:** The slope parent soil is leida clay, which is an unstable material and had caused the slope to erode substantially.

**soil type:** Leida clay, shallow depth of topsoil.

**hydrology:** Spring seepage along the bank.

**type of bioengineering structure:** Stop logs were placed perpendicular to slope and wired in place. Live stakes and live, bundled fascines were laid perpendicular to the slope and backfilled with a sandy loam. Fascines were 1.2 m to 1.8 m in length and 20 mm diameter.

**plant material:** Live stakes of Salix species and Populus species were from Ontario Ministry of Natural Resources nursery stool beds. Rhus typhina (Staghorn Sumac) rooted seedlings were also planted and the site was sodded after construction.

**post construction problems:** Some bare areas on slope and beaver damage to some plant material.

**site conditions at first visit:** The first site visit occurred as construction was finishing in the fall.

**site conditions at second visit:** The slope erosion is controlled. The stop logs are still in place and there is some growth of Populus species. The Rhus seedlings have grown and established themselves on the slope.

**survival of plant materials:** Some Salix species but mostly Populus species have grown from the live stakes and fascines. Rhus seedlings have predominantly populated the slope and there is a good cover of herbaceous perennial plants.

**success of the structure:** Good. The bioengineered structure has stopped the erosion and stabilized the slope. Both woody and herbaceous plants have started to colonize the site.

## Mooney's Bay

Photograph (1994) of site immediately after construction. From the top down, the Rhus (Sumac) seedlings, bundles of fascines, stop logs and live stakes are visible.

Photograph (1999) showing site has been successfully populated with various woody and herbaceous species. Stop logs are still visible.

# Site Name: Osler Bluff

## Type of Bioengineering Structure:

- ■ **Live Stakes**
- ❑ Brush Layers
- ❑ Brush Mattresses
- ■ **Live Fascines**
- ❑ Live Crib Walls
- ❑ Anchored Cut Conifers
- ❑ Root Wads

## Success of the Structure:

- ❑ Poor
- ■ **Fair**
- ■ **Good**
- ❑ Excellent

## Site Details:

| | |
|---|---|
| **location:** | Collingwood Twp., south of Osler Bluff, on the crest of the Niagara Escarpment |
| **contact:** | Rick Grillmayer, Nottawasaga Valley *Conservation Authority (705) 424-1479* |
| **date of construction:** | October 15, 1993 |
| **cost of construction:** | $8,000 |
| **first site visit:** | November 23, 1994 |
| **second site visit:** | November 23, 1999 |

**site characteristics:** A large area clear of vegetation and featuring the extensive formation of gullies and rills on steep clay and shale slopes of the Niagara Escarpment.

**site problems:** Site is steep with impervious, inorganic soils, resulting in quick surface runoff into a tributary of Black Ash Creek with a sediment transportation that degrades fish habitat.

**soil type:** Dunedin clay/shale mix, inorganic, infertile soils.

**hydrology:** A dry, upland site with impervious soils and quick surface runoff down numerous gullies.

**type of bioengineering structure:** Live fascines were gathered in various length bundles (up to 3 m to 4 m in length). Fascines were dug into perpendicular lines across the site and in the drainage gullies in the direction of flow. Live stakes were also located throughout the site.

**plant material:** Live stakes and fascines consisted of Salix eriocephala, Salix alba, Salix exigua, and hybrid species of Populus. They were stored in a pond and used within 2 days. Straw mulch and erosion control blanket was used as cover over annual ryegrass and oats which were seeded to encourage natural species invasion and regeneration.

**post construction problems:** Deer continually browse the area and take the tops off the Salix (Willow) shoots each winter.

**site conditions at first visit:** The site is extremely hostile to plant growth. The fascines have developed some top growth but all vegetation is sparse.

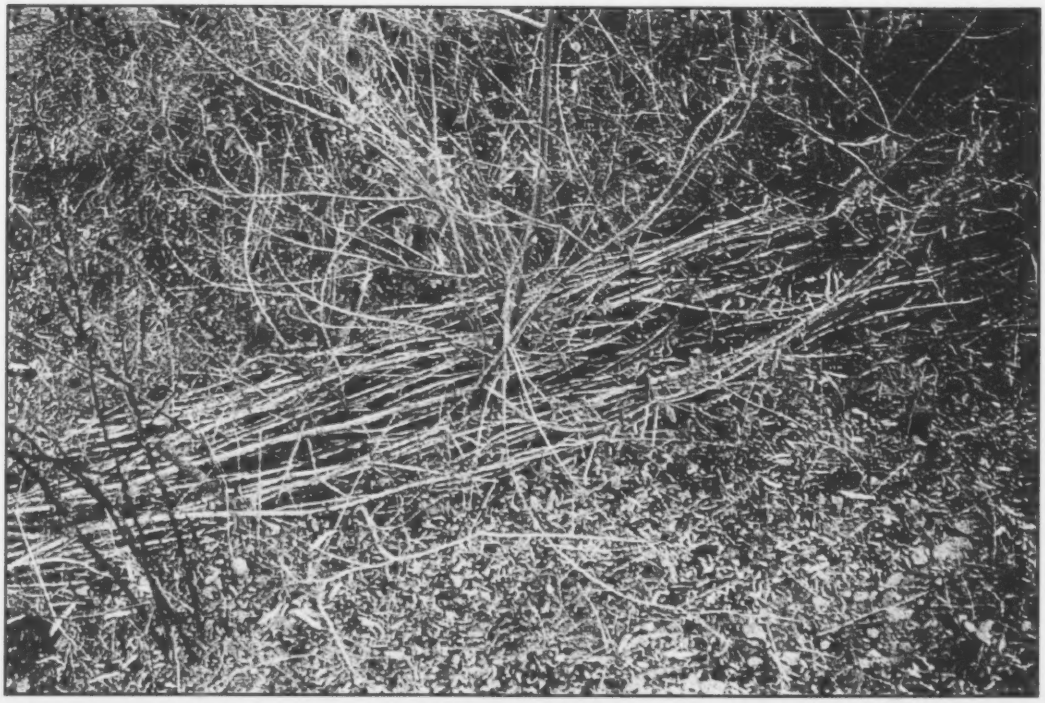
**site conditions at second visit:** The site is still extremely harsh to vegetation. The woody plants have slowly started to establish themselves. There is evidence of woody and herbaceous invasion by indigenous species. The fascines have rooted into the soil slope and still manage to control the gully and rill erosion. This is particularly evident where the fascines end and the gully erosion begins again.

**survival of plant materials:** Due to the extreme nature of the site, the woody plants are struggling to survive and grow. Salix and Cornus species are doing poor, the survival rate is about 30%. Populus species are growing better, the site conditions have moderated somewhat to support invasion and establishment of woody plants such as Robinia pseudoacacia (Black Locust) and indigenous herbaceous perennials.

**success of the structure:** Fair to Good. While the plant material has struggled to survive, the bioengineered structure is still in place and providing erosion protection. This is evident where the bioengineering ends and the runoff is allowed to meander and erode further down the gullies. Eventually woody and herbaceous plants should colonize the area but it will be a long hard battle given the extremely poor site conditions.

# Osler Bluff

Site photograph (1999) showing sterile soil, bundled fascines and invasive woody plants.



Photograph (1999) showing a close-up of bundled fascine.

# Site Name: Parliament Hill

## Type of Bioengineering Structure:

- ❑ Live Stakes
- ■ **Brush Layers**
- ❑ Brush Mattresses
- ❑ Live Fascines
- ❑ Live Crib Walls
- ❑ Anchored Cut Conifers
- ❑ Root Wads

## Success of the Structure:

- ■ **Poor**
- ■ **Fair**
- ❑ Good
- ❑ Excellent

## Site Details:

| | |
|---|---|
| **location:** | Ottawa, along Rideau Canal behind parliament buildings |
| **contact:** | Gerry Lajeunesse, National Capital Commission (613) 239-5139 |
| **date of construction:** | May 1, 1994 |
| **cost of construction:** | Unknown |
| **first site visit:** | December 1, 1994 |
| **second site visit:** | October 5, 1999 |

**site characteristics:** Steep slope (approx. 1.5:1) leading down to the Ottawa River. The slope is populated with invasive non-natives such as Acer platanoides (Norway Maple), which the NCC wanted to remove and replace with native plant species.

**site problems:** Storm sewer washout created the erosion problem and non-native vegetation had invaded the site over a period of time.

**soil type:** Shallow overburden, rock.

**hydrology:** Well drained, steep slope, storm sewer system down slope.

**type of bioengineering structure:** Stop logs (cedar with steel stakes and plastic netting) were installed in 1993. Brush layers were added in 1994. Erosion control blanket was placed on the soil slope.

**plant material:** Brush layers were mainly Salix shrub species.

**post construction problems:** Beaver damage to trees at the toe of slope near the Ottawa River. Wire cage guards were placed around existing and planted trees for beaver protection.

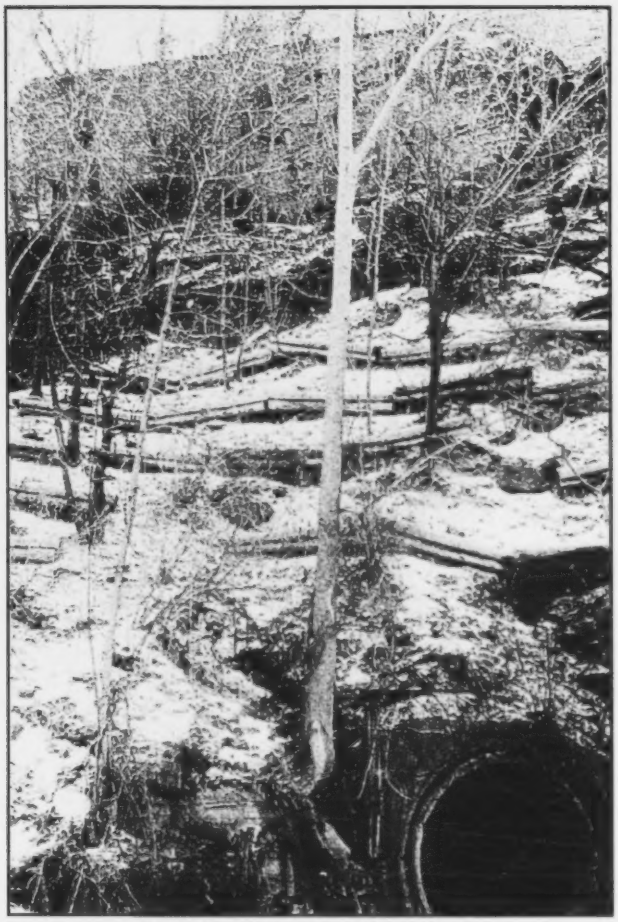
**site conditions at first visit:** The stop logs are still secure and holding the slope surface in place. Dense brush layering has been added to the east slope.

**site conditions at second visit:** Non-native vegetation has been removed from the southern section of the east slope and has been replaced with indigenous landscape plants. The stop logs are still functioning adequately, although some have been moved or removed. There was little evidence of growth from the brush layering.

**survival of plant materials:** There was little evidence of growth from the brush layering installation. The planted landscape materials appeared to be growing well.

**success of the structure:** Poor to Fair. While the slope has held, due in part to the stop logs, there have been interventions through the years to take remedial actions to specific erosion problems. The slope understory continues to be sparse under the wooded canopy. The cleared southern part of the east slope has developed a dense ground cover which is probably due to increased sunlight from the removal of the canopy cover.

## Parliament Hill



Photograph (1994) of slope showing stop logs.

Photograph (1999) of slope showing remnants of stop logs and sparse understory.

# Site Name: Sawmill Creek

## Type of Bioengineering Structure:

- ■ **Live Stakes**
- ■ **Brush Layers**
- ❑ Brush Mattresses
- ❑ Live Fascines
- ■ **Live Crib Walls**
- ❑ Anchored Cut Conifers
- ❑ Root Wads

## Success of the Structure:

- ❑ Poor
- ❑ Fair
- ❑ Good
- ■ **Excellent**

## Site Details:

| | |
|---|---|
| **location:** | Mississauga, NW corner Erin Mills Pkwy. and Burnhamthorpe Rd. |
| **contact:** | Bob Levesque, City of Mississauga (905) 896-5144 |
| **date of construction:** | October 1, 1996 |
| **cost of construction:** | $52,000 |
| **first site visit:** | November 22, 1996 |
| **second site visit:** | February 2, 2000 |

**site characteristics:** A section of an urban creek meandering through a woodlot and paralleled by a walking trail.

**site problems:** Meandering alignment had caused stream bank erosion.

**soil type:** Clay and shale.

**hydrology:** Creek is continuous flow with seasonal fluctuation in water levels.

**type of bioengineering structure:** A four level crib wall incorporating brush layers was placed along sections of the stream bank. Live stakes were planted back of the stream banks and in the floodplain area.

**plant material:** Brush layers were Salix shrub species and Cornus stolonifera. Live stakes were Salix species.

**post construction problems:** None

**site conditions at first visit:** The crib wall is secure and the plant material has rooted and is growing.

**site conditions at second visit:** The crib wall structure is still secure with minimal undercutting of the stream bank. The plant material is growing very well from crib structure.

**survival of plant materials:** Salix species are growing very strong out of the two or three top crib wall layers. There is some Cornus stolonifera mixed in with the Salix species, probably no more than 10%.

**success of the structure:** Excellent. The crib wall is still structurally sound. The plant material is growing well and erosion and undercutting of the bank and crib wall is minimal.

Photograph (1999) of live crib wall along creek.

Photograph (1999) of Salix (Willow) shrub growth from brush layers in crib wall.

# Site Name: Sheridan Creek

## Type of Bioengineering Structure:

- ❑ Live Stakes
- ■ **Brush Layers**
- ❑ Brush Mattresses
- ❑ Live Fascines
- ❑ Live Crib Walls
- ❑ Anchored Cut Conifers
- ❑ Root Wads

## Success of the Structure:

- ❑ Poor
- ❑ Fair
- ❑ Good
- ■ **Excellent**

## Site Details:

| | |
|---|---|
| **location:** | Mississauga, Meadow Wood south off Lakeshore Rd., east of Southdown Rd. |
| **contact:** | Glenn Harrington, Harrington and Hoyle Ltd. (905) 294-8282 |
| **date of construction:** | December 1, 1991 |
| **cost of construction:** | $60,000 |
| **first site visit:** | November 15, 1994 |
| **second site visit:** | February 2, 2000 |

**site characteristics:** A steep slope leading from residential development on the upper plateau down to Sheridan Creek, a relatively large creek that feeds into Rattray Marsh.

**site problems:** Steep slope from old meander scar of the creek was too close to the toe of slope and the residential area at the top of slope.

**soil type:** Sandy loam.

**hydrology:** Minor seepage one third of the way up the slope. Surface runoff over the slope.

**type of bioengineering structure:** Brush layers were trenched in across the slope and a straw mulch was used on the slope soil surface.

**plant material:** Brush layers were hybrid species of Populus, Populus balsamifera, Cornus stolonifera, Salix eriocephela and Salix discolour. Plant material was sourced from the Credit River Conservation Authority, cut and used same day.

**post construction problems:** None.

**site conditions at first visit:** Approximately 60 to 80% of the plant material had survived and was growing well and stabilizing the soil slope surface.

**site conditions at second visit:** There is good survival of the Populus hybrid species from the original brush layers. The slope has been populated by indigenous invasive herbaceous and woody plants. There is no evidence of erosion.

**survival of plant materials:** There is good survival of the Populus hybrid species from the original brush layers. The largest trees are 10 m high and 300 mm in diameter. The brush layers have been harvested and the top growth has been cut and removed. There is ample suckering from the stumps and the new top growth is healthy and lush.

**success of the structure:** Excellent. The brush layers have held the slope, erosion is not evident. There is good top growth from the cut stumps of the brush layers and invasive herbaceous and woody plants are moving in.

## Sheridan Creek

Photograph (2000) of site showing steep slope from residential property down to creek valley.

Close-up photograph (2000) of brush layers showing cut stumps and suckering growth of Populus (Poplar) trees.

# Site Name: Thamesville

## Type of Bioengineering Structure:

- ■ **Live Stakes**
- ❑ Brush Layers
- ❑ Brush Mattresses
- ■ **Live Fascines**
- ❑ Live Crib Walls
- ❑ Anchored Cut Conifers
- ❑ Root Wads

## Success of the Structure:

- ❑ Poor
- ■ **Fair**
- ■ **Good**
- ❑ Excellent

## Site Details:

| | |
|---|---|
| **location:** | Thamesville, Hwy. 2 and County Rd. 21 |
| **contact:** | MNR Chatham Area Office<br>(519) 354-7340 |
| **date of construction:** | May 1, 1993 |
| **cost of construction:** | Unknown |
| **first site visit:** | November 1, 1994 |
| **second site visit:** | November 9, 1999 |

| | |
|---|---|
| **site characteristics:** | The site features a small creek in a larger floodplain that flows across an adjacent cattlefarm and feeds into the Thames River. |
| **site problems:** | Stream bank erosion along meandering section of creek. |
| **soil type:** | Sandy loam. |
| **hydrology:** | Low flow, some seasonal fluctuation in flow and levels. |
| **type of bioengineering structure:** | Live fascines were used on the stream banks and live stakes were planted back of the stream banks and adjacent to the creek in the floodplain. |
| **plant material:** | Several Salix shrub species were used in the fascines and as live stakes. Cornus stolonifera was also used in the fascines. All plant material was kept in cold storage until used. |
| **post construction problems:** | Rooted whips 1.25 m in height were planted in tubex shelters along the northwest side of the creek. Rooted trees planted in tubex shelters were dead at the 1999 site review. |
| **site conditions at first visit:** | There is fairly good survival of the fascines and rooted whips. |
| **site conditions at second visit:** | Good survival of Salix shrub species from the fascines on southeast side of creek. Live stake success is poor and the rooted whips are mostly dead. |
| **survival of plant materials:** | Salix shrub species are generally in good condition. Shrubs average 3 m to 5 m in height and up to 100 mm in diameter. There is no Cornus stolonifera in evidence. |
| **success of the structure:** | Fair to Good. Further stream bank erosion has been prevented, there is no major erosion evident and the creek is shaded. |

## Thamesville

Photograph (1999) showing close-up of stream bank and Salix (Willow) shrubs growing from live stakes.

Overview photograph (1999) from County Road 21 looking over creek, Salix (Willow) shrub growth and floodplain.

## Summary Observations

All eighteen sites reviewed have been successful as long term alternatives to traditional erosion control methods. Obviously, the degree of success varies with each project, however, none of the projects have outright failed. The plant material success varies quite a lot across the board and is more indicative of the relative severity of each site. Generalizations can be made about the success of each of the bioengineering techniques.

### Live Stakes

The success of live stake plantings depends, to a great degree, upon the selection of plant material, the time of cutting, storage treatment and method of installation. The more successful live staking tends to be from local sources, cut during dormant periods, installed immediately after cutting and driven into the soil carefully with a dead blow or soft lead shot mallet. Root growth is normally quite vigorous in the first year with moderate top growth. Second year growth is more balanced as the roots can provide more support for branch and leaf development. The use of a rooting hormone is not substantiated as an obvious benefit. Mortality of live stakes can be quite high, however the initial cost is very low. This would tend to indicate that live stakes should be overplanted initially, fully expecting approximately a 25% mortality rate. Where evident, deer, rabbits and beaver can decimate live stake plantings and steps should be taken to guard the plants from browsing and rodents.

### Brush Layers

Brush layers were probably the most commonly used bioengineering technique on the projects that were reviewed. Brush layers have been trenched into slopes horizontally, at various angles to the slope, vertically and as brush layer packing between log crib walls. Brush layers are easiest to install, not needing to be driven into the soil or bundled, tied and secured.

Cuttings for brush layers are usually taken during plant dormancy early in the spring and the cuttings are stored in water for up to three days. Some of the case studies had taken the cuttings earlier and placed them in cold storage.

Trench excavation, backfilling and firming of the backfill ensures good soil contact. With sufficient moisture the brush layers root and exhibit some top growth in the first year. Over successive growing seasons the plant material in the brush layers becomes more entrenched in the site location, whether part of a crib wall or as a linear brush layer trench. The older top growth tends to die off or die back and new top shoots sucker from the base of older branches. While this is not an ideal horticultural specimen, it does tend to be sustainable as a woody plant. Once the roots have established themselves, it may be beneficial to top-prune or cut back the top growth to promote new shoot suckering. This was done at the Sheridan Creek site where hybrid Populus species were used. For a brush layer, the intent is not to grow a large tree, but rather small, multi-stemmed trees or large shrub forms of woody plant material. Cutting back the top growth was a good idea.

## Brush Mattresses

Brush mattresses are very similar to the brush layers in terms of source material, care and handling and growth characteristics. Most of the comments made about brush layers also apply to brush mattresses. The main difference is that while brush layers are trenched in layers across the fall of a slope or trenched in gaps in crib walls, brush mattresses are used to re-vegetate a whole slope area.

## Live Fascines

Source plant material for live fascines was obtained in a manner similar to that for brush layers and brush mattresses. The key point again appears to be fresh, succulent, dormant cuttings of suitable species. The plant material is kept moist or in cold storage until installation.

In the case studies, bundles of live fascines were placed in drainage courses down a slope, in trenches across the face of a slope, in stream banks at the bottom and top of the slope or in conjunction with a crib wall structure. The theory of live fascines is that most of the bundle of fresh, succulent branches is buried. The branches produce both top growth and root growth through adventitious buds located all along the length of the branch. This tends to work really well if plant species are used that lend themselves to this type of growth. Salix species tend to be the best plant material for fascines, however, Populus and Cornus can also root and grow quite well from live fascine bundles. The fascines in the case studies have grown well, producing abundant top growth and substantial root development that both secures the immediate soil area thereby reducing erosion, as well as moving water out of the soil through transpiration. One of the concerns with live fascine growth is that the top growth of the plant may become weak over time as the plant continues to grow. The adventitious buds throw out new branches and as these grow they turn up to grow vertically. This results in almost a ninety degree bend in the branch as it leaves the fascine. It is an obvious weak point for damage and breakage. Corrective pruning may minimize the problem and new roots thrown out from the vertical branch may provide for a more structurally stable plant.

## Live Crib Walls

Live crib walls in the case studies are used exclusively along stream bank edges where water erosion from flow velocity and fluctuating levels has caused stream bank erosion. Crib wall construction is a major cost of bioengineering projects, however it is not expected to be a permanent solution. The idea is that the crib wall will secure the stream bank, prevent erosion and welcome the deposition of transported sediments over time. The crib wall will also allow plant materials to root and develop within the structure of the crib wall. As the crib wall materials age and weather, the growing plants will assume control of the stream bank. After a period of time, the crib wall self-destructs and hopefully by this time, the plant material has established and is now strong enough with a well developed root system to protect the stream bank. Most of the case studies had crib walls that were exhibiting these properties. Many of the projects were five years old and the crib walls were still structurally sound, some had undercutting and washouts, but this was not considered serious and the brush layers, fascines and invasive plants were growing well within the crib wall structure.

### Anchored Cut Conifers

The use of anchored cut conifers does not employ live plants as part of the design. The concept of placing dead trees into a stream, at an angle to the flow, is to disrupt the velocity of the stream. This treatment creates eddies and protected pockets in the lee of the flow that will enhance fish habitat and create areas for transported sediment deposition. The cut trees are anchored back into the stream bank. It is in these areas where live stakes and other rooted landscape plants are employed to enhance the stream cross-section and provide shade and stability of the soil slope. This technique appears to work quite well and has survived several seasonal cycles.

### Root Wads

As with the anchored cut conifers, the use of root wads does not employ live plants. The principle of root wads is that the root structure of a dead tree is used to protect strategic stream bank sections of a watercourse. Root wads are normally used on the outside bend of a watercourse where the undercutting and stream bank erosion is worse. The root wads do not interfere as much with the stream flow as the cut trees, however they do protect the bank and offer areas for the deposition of sediment and the establishment of indigenous plant material in the vicinity of the root wad. The root wads have also survived several seasonal cycles and appear to be doing the job well.

## Summary Recommendations

The study of eighteen, different soil bioengineering projects over a five year period shows that the techniques employing living plants to secure slopes and stream banks does work.

The dynamic nature of the design solutions allows for flexibility in the physical design without compromising structural integrity. Proponents of bioengineering argue that this dynamic solution is actually stronger over time than conventional hard engineering.

The conventional engineering design solution offers a significant comfort level to the property owner and the designer. Engineering is a science and erosion control methodologies can be quantified. In addition, conventional hard engineering solutions are "familiar, comfortable things to create with a reasonably known performance level" (Timothy S. Patterson, February 1999). The traditional method is also costly, static, usually unappealing and not always environmentally acceptable. Public opinion on design solutions has been changing with the advent of environmental assessment, the public now acknowledges that aesthetics and context-sensitive design are as important as solving the problem.

Soil bioengineering offers an alternative design solution that does fit in with its surroundings. It does not stand out for being an out-of-place element in a natural setting. Soil bioengineering is less costly to install than hard engineering structures and it has the ability to mature and strengthen over time. A bioengineered solution can also repair itself when parts become damaged. However, bioengineered structures are unfamiliar to most property owners and designers when faced with an erodible situation. Unfamiliarity leads to a lack of confidence in the ability of logs, sticks and plants to control erosion situations where concrete, rock and steel have always been used. Added to the unfamiliarity of the technique is the fact that the sticks and dormant plants have to grow to be successful. The 'bio" part of bioengineering is daunting to those unfamiliar with horticultural practices.

Notwithstanding the above concerns with bioengineered structures, the eighteen case studies show that these designs can stand the test of time. Vegetative bank stabilization can be achieved if the following points are understood and followed:

**1. Evaluate and Assess the Project**

A thorough problem evaluation and design assessment should be undertaken. Bioengineering techniques require certain conditions in micro-climate, exposure to sun, soil moisture, soil fertility and protection from animals and humans. Soil bioengineering is not an environmental panacea. It is not the best solution for every soil erosion or stream bank problem.

**2. Employ Experts**

Designers with training and experience in civil engineering and one of the natural sciences such as landscape architecture, horticulture or biology should be employed to assess the problem and recommend a solution.

**3. Establish Timing**

Timing is critical for bioengineered projects. Timing both in terms of the actual cutting of the source material, its storage and use, as well as the timing of the construction of the bioengineered structure.

**4. Establish Labour Component**

Most bioengineering techniques employ large amounts of hand labour to harvest the source material, store the materials and construct the bioengineering structures. While local labour is relatively inexpensive compared to skilled labour to operate complex construction equipment, care should be taken to educate the labour force and ensure that qualified 'bioengineering' staff are on site to control the operation.

**5. Maintain Completed Project**

Maintenance of the completed project should be included in the design estimate. While bioengineered sites do not require a great deal of maintenance, the finished project needs to be reviewed periodically to evaluate the success of the living structure. Living materials can be damaged by human intervention (vandalism or mowing/brushing operations), animals (beaver, rabbits, mice, deer) or natural occurrences such as drought, flooding or climactic change. Some bioengineering materials may need to be "cut back" or pruned occasionally to avoid too much top growth or an unhealthy or unsafe plant.

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